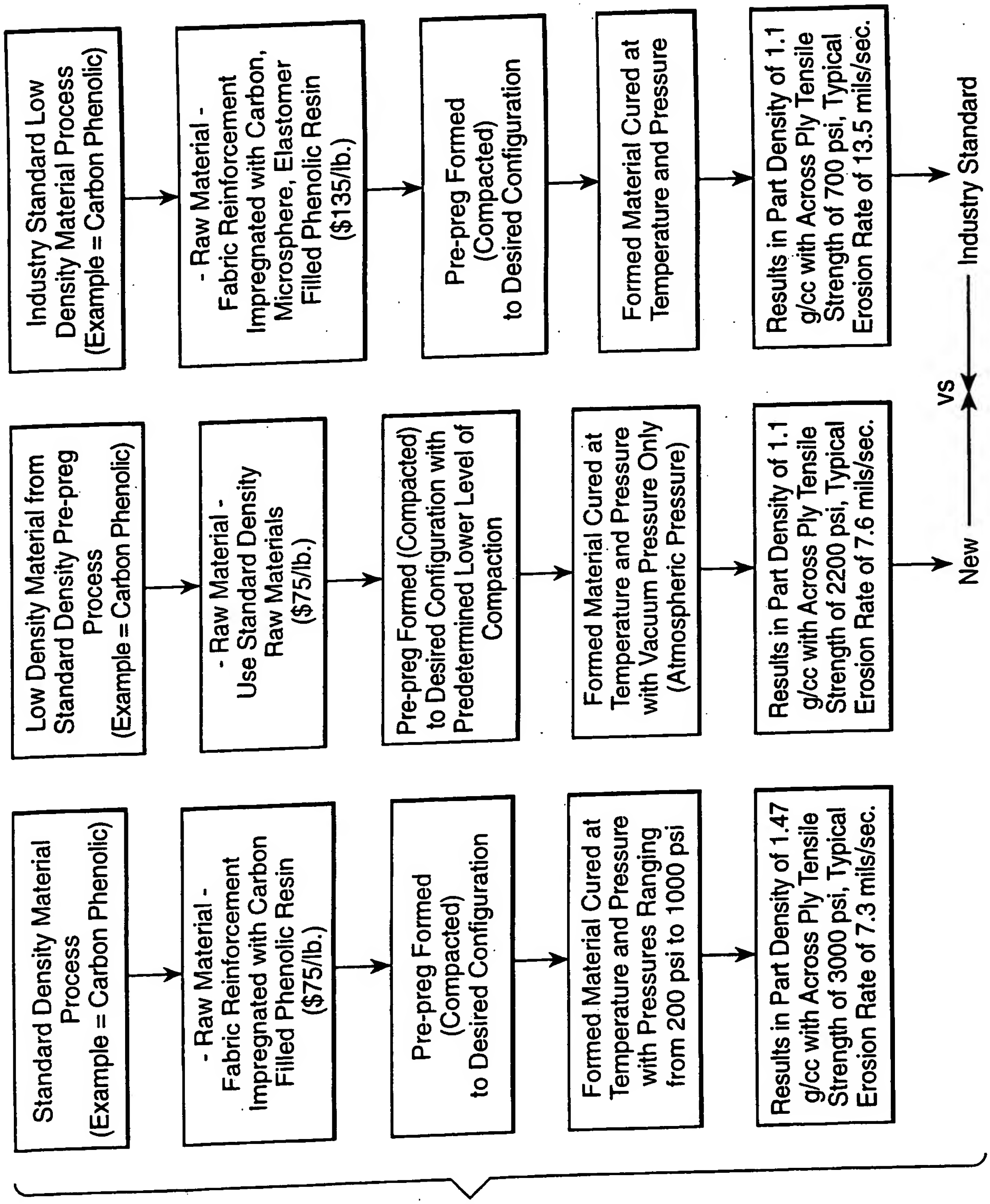
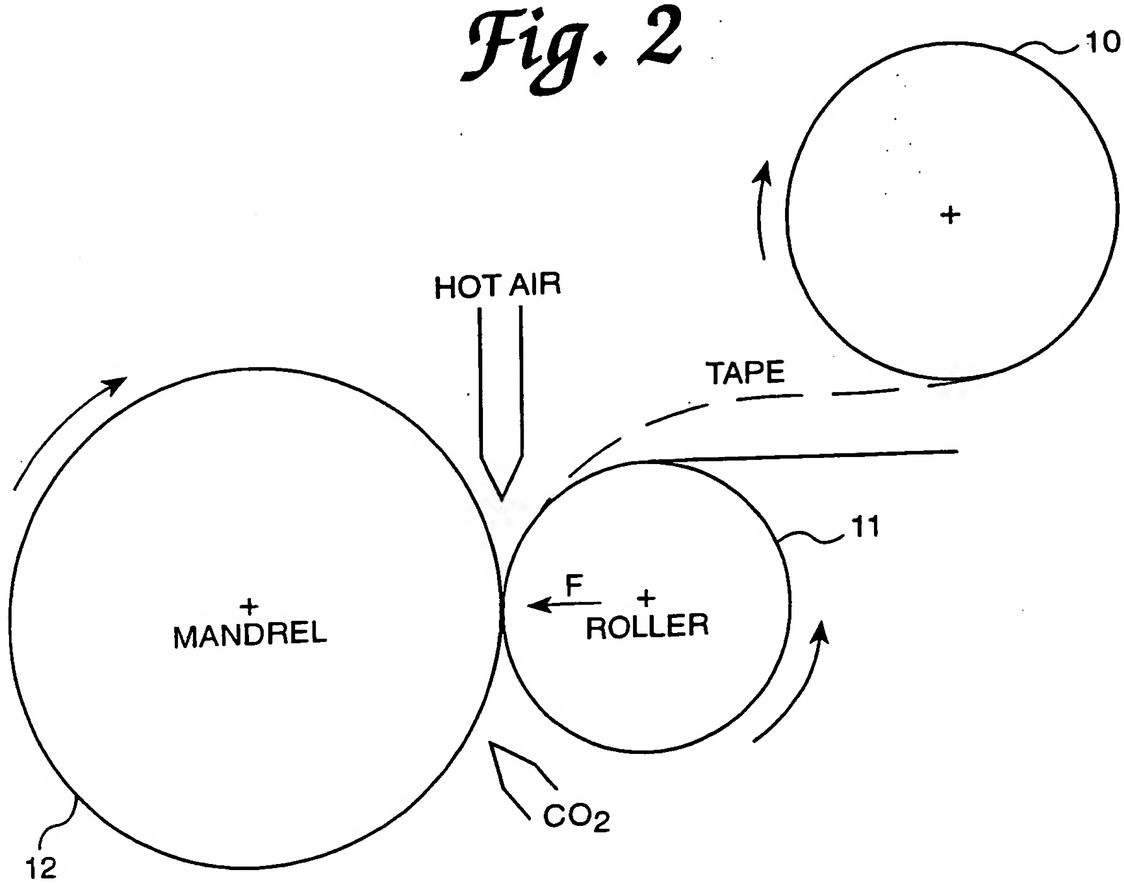


Standard Density Material Process (Example = Carbon Phenolic)
- Raw Material - Fabric Reinforcement Impregnated with Carbon Filled Phenolic Resin ($75/lb.)
Pre-preg Formed (Compacted) to Desired Configuration
Formed Material Cured at Temperature and Pressure with Pressures Ranging from 200 psi to 1000 psi
Results in Part Density of 1.47 g/cc with Across Ply Tensile Strength of 3000 psi, Typical Erosion Rate of 7.3 mils/sec.
Low Density Material from Standard Density Pre-preg Process (Example = Carbon Phenolic)
- Raw Material - Use Standard Density Raw Materials ($75/lb.)
Pre-preg Formed (Compacted) to Desired Configuration with Predetermined Lower Level of Compaction
Formed Material Cured at Temperature and Pressure with Vacuum Pressure Only (Atmospheric Pressure)
Results in Part Density of 1.1 g/cc with Across Ply Tensile Strength of 2200 psi, Typical Erosion Rate of 7.6 mils/sec.
New
vs
Industry Standard
Industry Standard Low Density Material Process (Example = Carbon Phenolic)
- Raw Material - Fabric Reinforcement Impregnated with Carbon, Microsphere, Elastomer Filled Phenolic Resin ($135/lb.)
Pre-preg Formed (Compacted) to Desired Configuration
Formed Material Cured at Temperature and Pressure
Results in Part Density of 1.1 g/cc with Across Ply Tensile Strength of 700 psi, Typical Erosion Rate of 13.5 mils/sec.

Fig. 1

Fig. 2



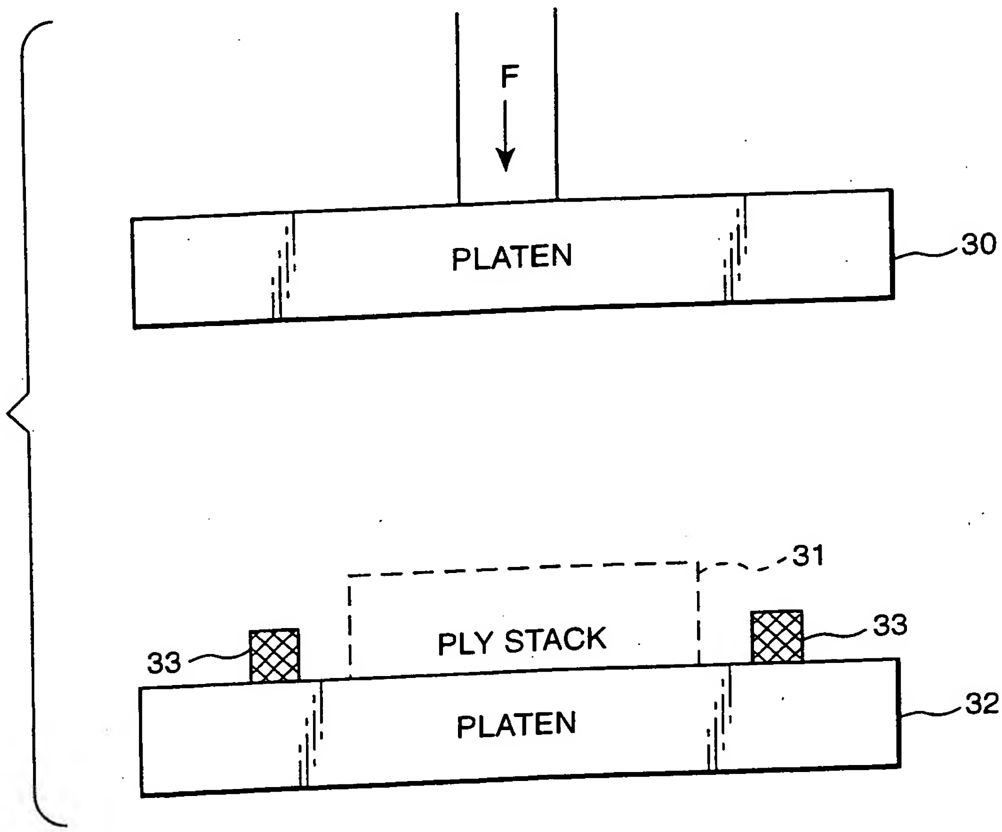
A. A wrap mandrel is placed in the machine (a wrap machine looks much like a lathe).

B. The tape application roller is set parallel to the wrapping surface of the mandrel.

C. Tape is fed across the surface of the application roller

- Pre-preg tape is heated with hot air as it crosses over the roller to soften the tape.
- Pressure is applied through the roller to debulk the tape onto the wrap mandrel.
- CO_2 from a liquid holding tank is applied to cool and harden the debulked tape.

Fig. 3



A. A stack of plies is placed in the heated platen press for debulk.
   - Platen are warmed to 130 - 150°F to soften pre-preg.
   - Stops are set to restrict platen travel and to achieve desired debulked ply thickness.

B. Press platen are closed to stops and held at temperature for 20 min.

C. Debulked stacks are cooled to room temperature before opening platen.

D. Debulked stacks are stacked to form entire billet.

Fig. 4A

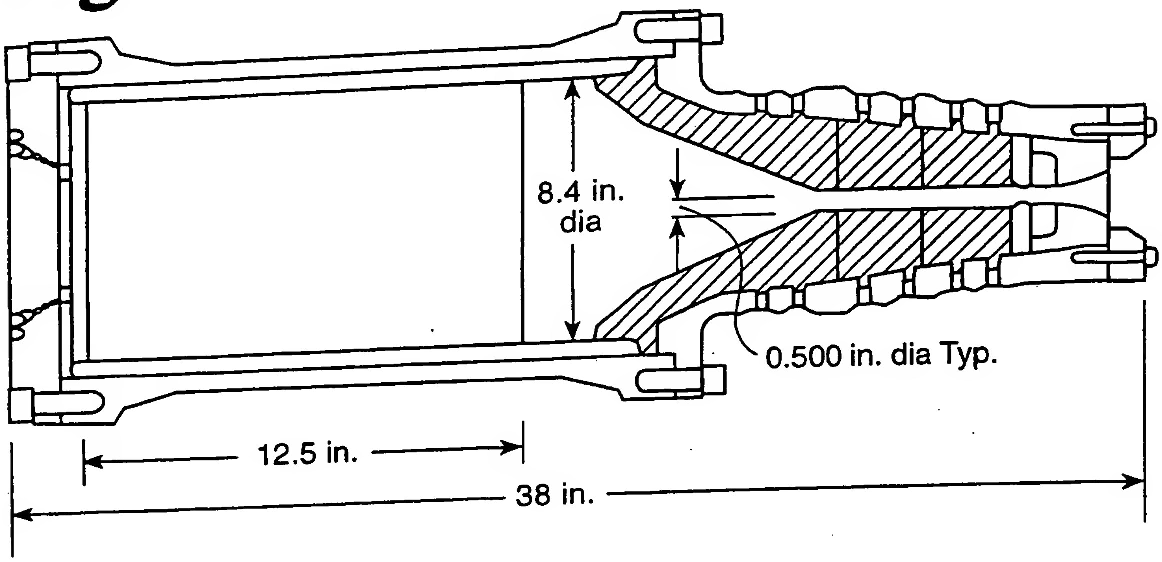


Fig. 4B

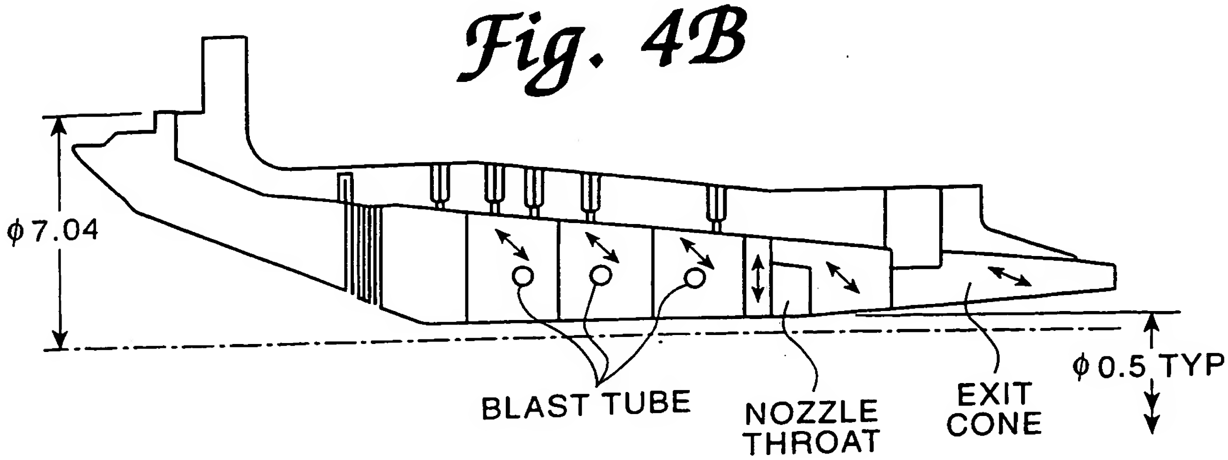


Fig. 4C

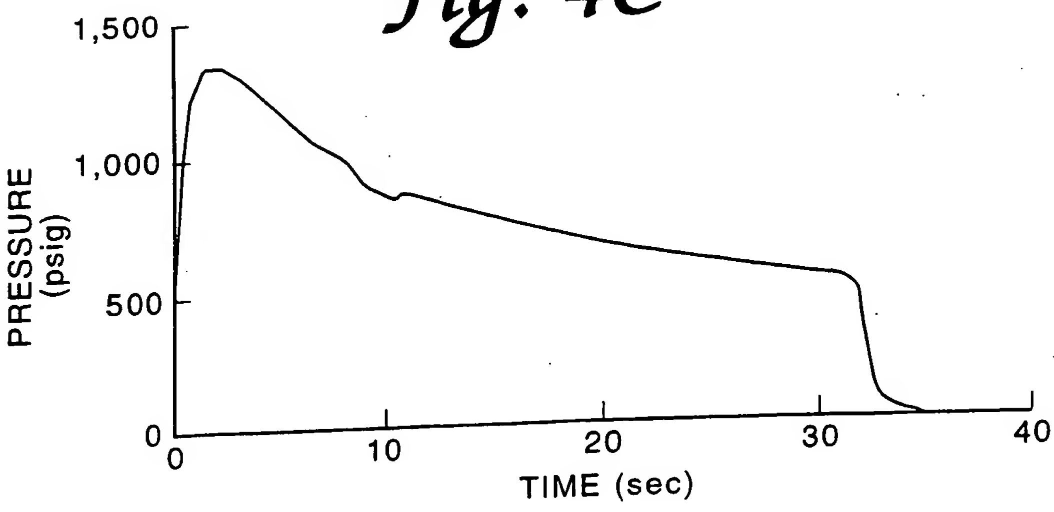


Fig. 5

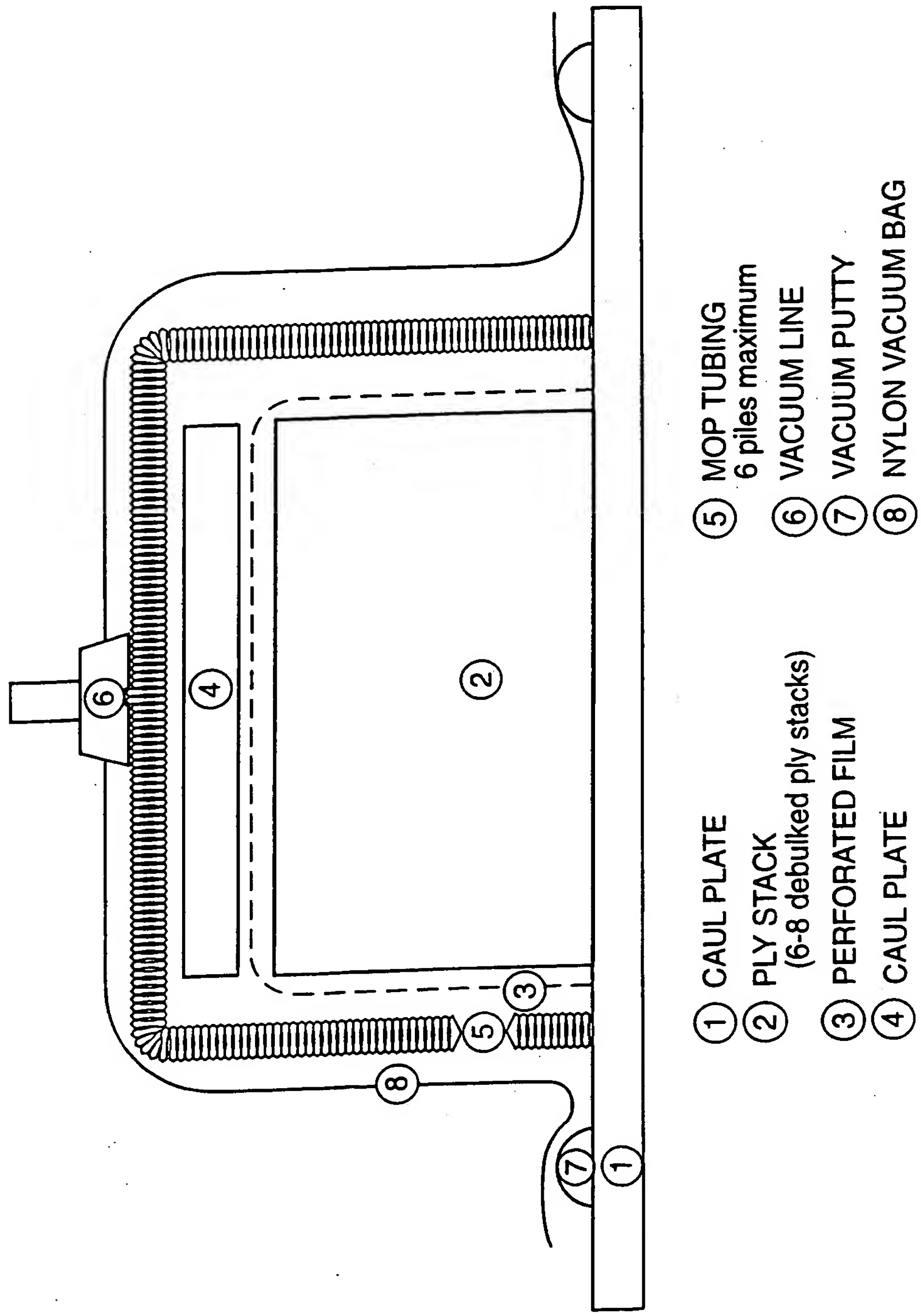

1 CAUL PLATE
2 PLY STACK (6-8 debulked ply stacks)
3 PERFORATED FILM
4 CAUL PLATE
5 MOP TUBING 6 piles maximum
6 VACUUM LINE
7 VACUUM PUTTY
8 NYLON VACUUM BAG

Fig. 6A

Component	Motor	Material	Norm. Erosion, mils/s	Norm. Char. inches	Total Heat Affected Depth, inches
Blast Tube-Aft	MPCE-1	MX-4946	2.39	0.409	0.493
	MPCE-2	MX-4926 VC	7.59	0.268	0.534
	MPCE-3	MX-4920 VC	6.18	0.464	0.680
	MPCE-4	UF MX-134 LDR (1.2)	11.03	0.234	0.620
	MPCE-5	UF MX-4920	5.32	0.483	0.669
	MPCE-6a	FM-32800 LD/LF	12.18	0.255	0.681
	MPCE-6b	MX-4955	8.65	0.398	0.701
	MPCE-7	MX-4946 VC	6.10	0.386	0.599
	MEAN	MX-4926	7.25	0.283	0.537
Blast Tube-Mid	MPCE-1	MX-4946	9.32	0.464	0.790
	MPCE-2	MX-4926 VC	10.49	0.301	0.668
	MPCE-3	MX-4920 VC	6.56	0.761	0.991
	MPCE-4	UF MX-134 LDR (1.2)	15.60	0.299	0.845
	MPCE-5	UF MX-4920	9.28	0.582	0.907
	MPCE-6	FM-32800 LD	13.97	0.205	0.694
	MPCE-7	MX-4946 VC	8.22	0.496	0.784
Blast Tube-Fwd	MPCE-1	MX-4946, 45	5.88	0.278	0.484
	MPCE-2		7.30	0.246	0.502
	MPCE-3		6.16	0.319	0.535
	MPCE-4		7.67	0.244	0.512
	MPCE-5		7.71	0.322	0.592
	MPCE-6		9.16	0.283	0.604
	MPCE-7		6.90	0.288	0.530
	MEAN	MX-4926	7.25	0.283	0.537
Throat	Typical	4D C/C . 1.95 gm/cc	2.50		
	MPCE-1	4D C/C . 1.90 gm/cc	1.20		
	MPCE-2	RTM'd 4D C/C, 1.75 gm/cc	6.12		
	MPCE-3	Compolent Hf/2W	0.81		
	MPCE-4	2D C/C Brake, 1.87 gm/cc	3.98		

Fig. 6B

Component	Motor	Material	Norm. Erosion, mils/s	Norm. Char. inches	Total Heat Affected Depth, inches
Throat	MPCE-5	HfC on Poco Graphite	7.26		
	MPCE-6	ZIRCONIUM DIBORIDE	7.76		
	MPCE-7	Insitu C/C by PL RD	5.01		
Throat Inlet	MPCE-1	MX-4926, 90	6.73		
	MPCE-2		9.94	0.341	0.543
	MPCE-3		8.97	0.364	0.678
	MPCE-4		7.50	0.562	0.896
	MPCE-5		11.90	0.617	1.033
	MPCE-6		8.76	0.700	0.963
	MPCE-7		7.41	0.330	0.589
Forward Exit Cone	MPCE-1	MX-4946, 45	4.24	0.216	0.364
	MPCE-2		4.00	0.260	0.400
	MPCE-3		12.74	0.216	0.682
	MPCE-4		4.62	0.211	0.350
	MPCE-5		3.72	0.340	0.430
	MPCE-6		4.73	0.190	0.356
	MPCE-7		3.42	0.297	0.417
Aft Exit Cone	C4-7	MX-4946	7.65	0.295	0.563
	MPCE-1	MX-4926	4.22	0.193	0.341
	MPCE-2a	MX-4920 VC	3.05	0.219	0.326
	MPCE-2b	MX-4926 VC	5.42	0.269	0.459
	MPCE-3a	UF MX-4920 VC	6.73	0.254	0.677
		UF MX-4920	6.37	0.292	0.991
	MPCE-4a	UF MX-134 LDR (1.2)	4.54	0.272	0.431
	MPCE-4b	UF MX-4920 VC & PC	4.57	0.344	0.504
	MPCE-5a	FM-32800 LD/LF	4.11	0.285	0.429
	MPCE-5b	UF MX-134 LDR (1.2) PC	4.15	0.258	0.400
	MPCE-6a	MX-4926 VC & PC	4.94	0.352	0.525
	MDCE-6b	FM-32800 LD/LF PC	4.93	0.270	0.443
	MPCE-7a	MX-4955 VC	3.24	0.420	0.534
	MPCE-7b	MX-4946 VC	3.42	0.360	0.484

Fig. 7

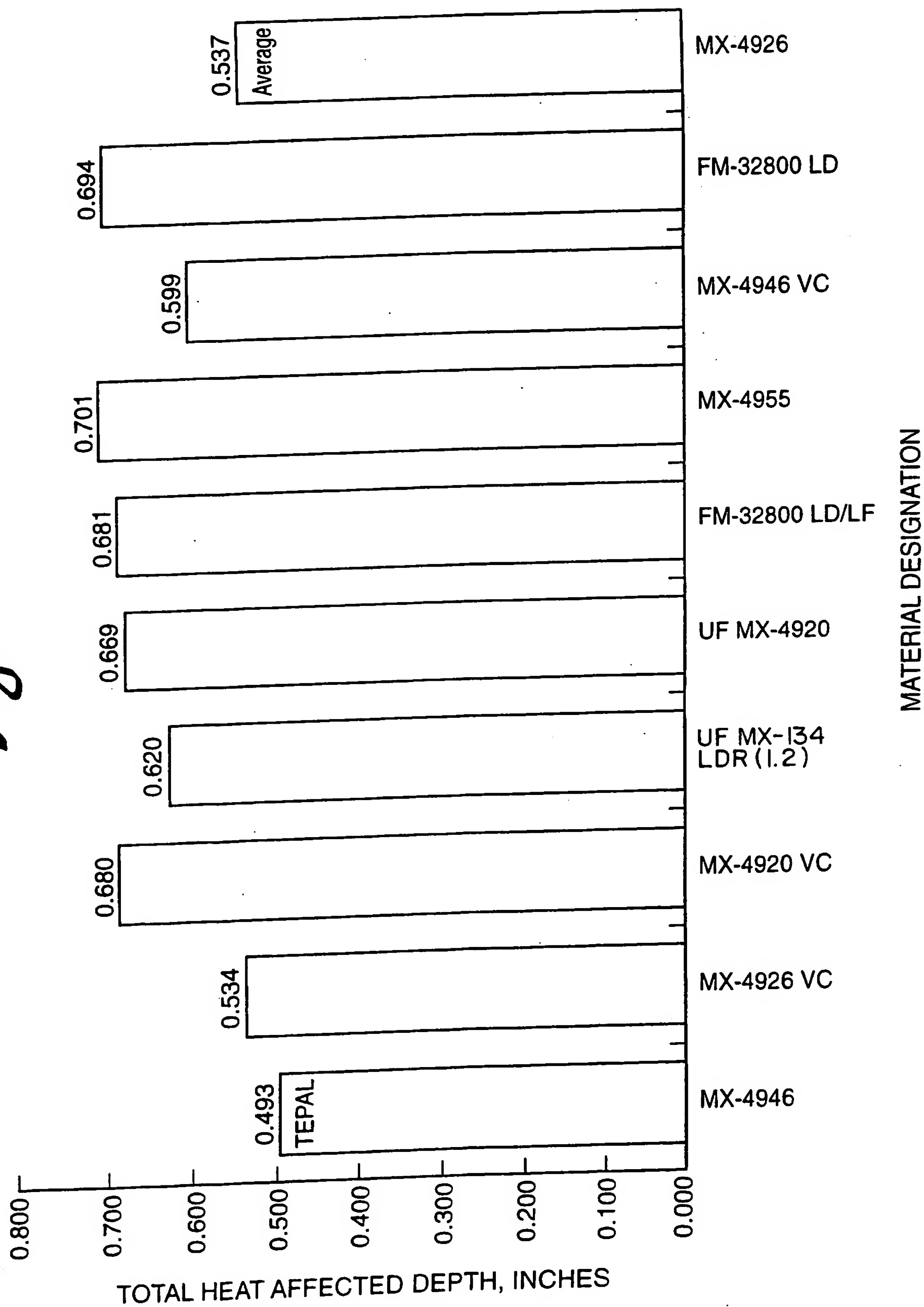
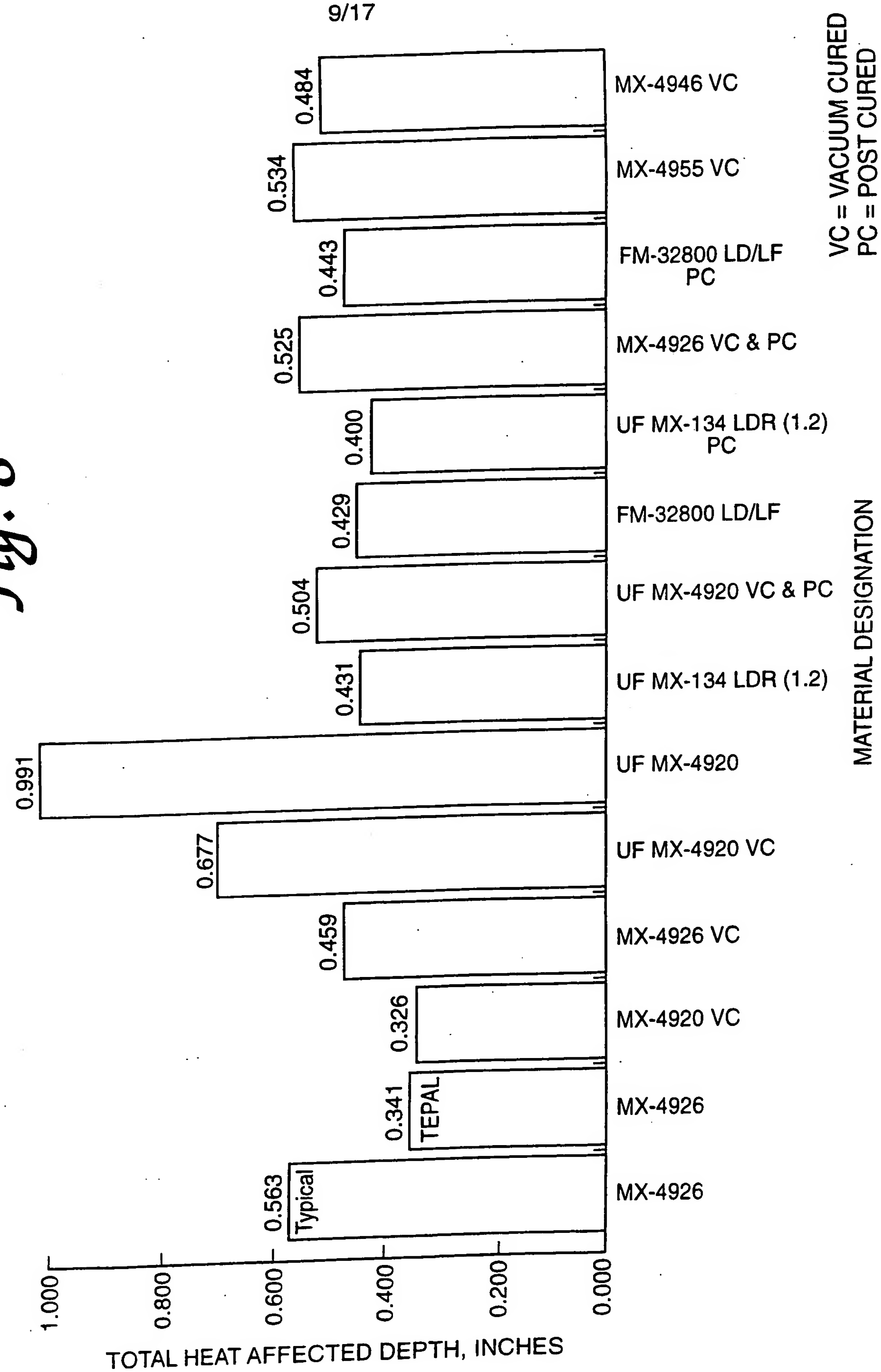
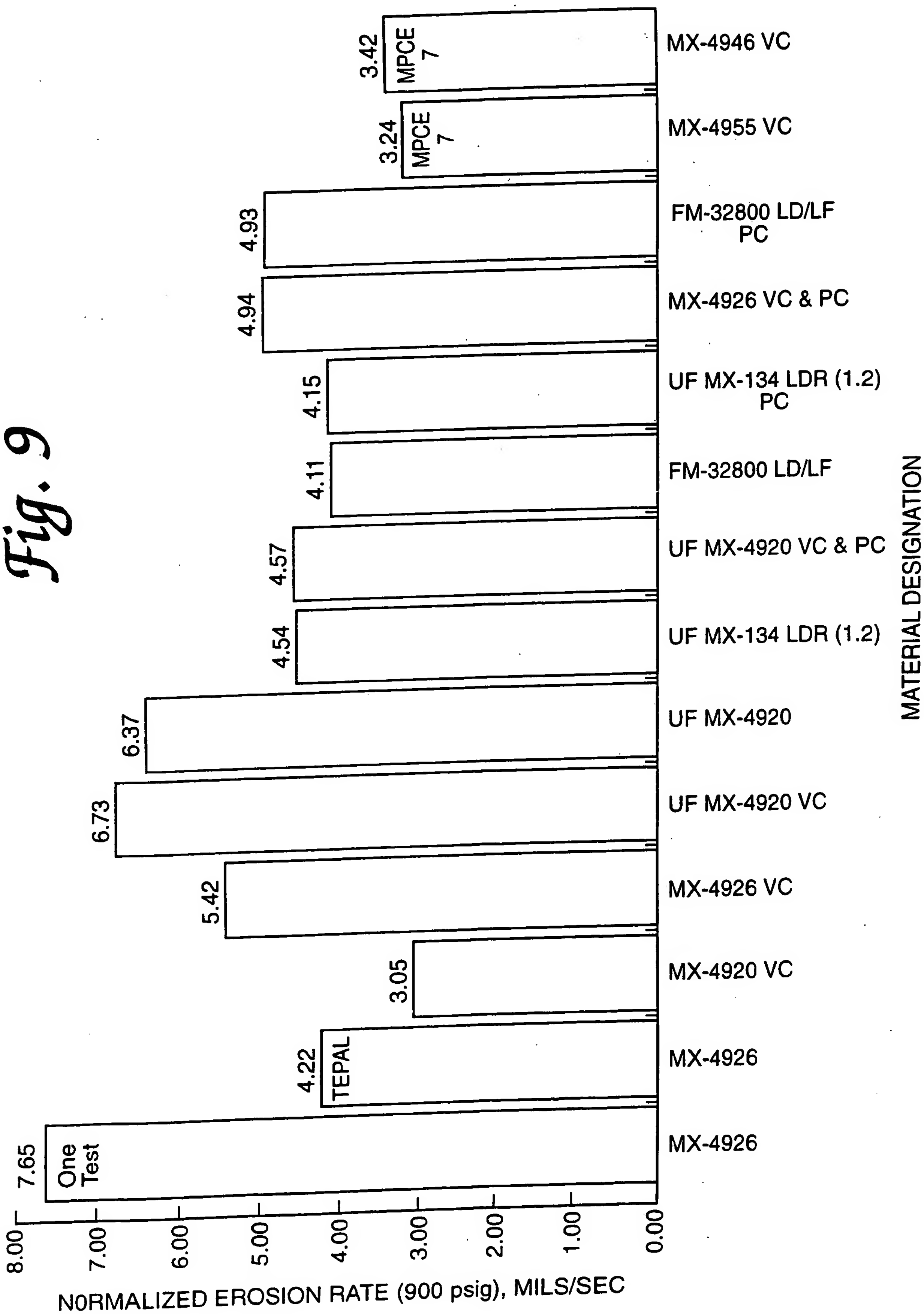

MATERIAL DESIGNATION
MX-4926
0.537
Average
FM-32800 LD
0.694
MX-4946 VC
0.599
MX-4955
0.701
FM-32800 LD/LF
0.681
UF MX-4920
0.669
UF MX-134 LDR (1.2)
0.620
MX-4920 VC
0.680
MX-4926 VC
0.534
MX-4946
0.493
TEPAL
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
TOTAL HEAT AFFECTED DEPTH, INCHES

Fig. 8


VC = VACUUM CURED
PC = POST CURED
MATERIAL DESIGNATION
MX-4946 VC
0.484
MX-4955 VC
0.534
FM-32800 LD/LF PC
0.443
MX-4926 VC & PC
0.525
UF MX-134 LDR (1.2) PC
0.400
FM-32800 LD/LF
0.429
UF MX-4920 VC & PC
0.504
UF MX-134 LDR (1.2)
0.431
UF MX-4920
0.991
UF MX-4920 VC
0.677
MX-4926 VC
0.459
MX-4920 VC
0.326
MX-4926
0.341
TEPAL
MX-4926
0.563
Typical
1.000
0.800
0.600
0.400
0.200
0.000
TOTAL HEAT AFFECTED DEPTH, INCHES



MX-4946 VC
3.42
MPCE 7
MX-4955 VC
3.24
MPCE 7
FM-32800 LD/LF PC
4.93
MX-4926 VC & PC
4.94
UF MX-134 LDR (1.2) PC
4.15
FM-32800 LD/LF
4.11
UF MX-4920 VC & PC
4.57
UF MX-134 LDR (1.2)
4.54
UF MX-4920
6.37
UF MX-4920 VC
6.73
MX-4926 VC
5.42
MX-4920 VC
3.05
MX-4926
4.22
TEPAL
MX-4926
7.65
One Test
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
NORMALIZED EROSION RATE (900 psig), MILS/SEC
MATERIAL DESIGNATION

Fig. 9

Fig. 10A

Location	Motor	Material	Bulk Density, gm/cc	Specific Gravity	Residual Volatiles, wt%	Resin Content, wt%	Compressive Strength, psi	Norm. Erosion mils/s	Norm. Char, inches	Thad, inches
Blast Tube, 45	MPCE-1	MX-4946	1.495	1.525	2.14	31.29	21379	2.39	0.409	0.493
	MPCE-2	MX-4926 VC	1.142	1.167	2.27	33.04	19749	7.59	0.268	0.534
	MPCE-3	MX-4920 VC	1.383	1.434	0.30	27.18	23067	6.18	0.464	0.680
	MPCE-4	UF MX-134 LDR	1.211	1.241	1.81	41.48	18520	11.03	0.234	0.620
	MPCE-5	UF MX-4920	1.454	1.496	1.94	33.23	17057	5.32	0.483	0.669
	MPCE-6	FM-32800 LD/LF	1.193	1.227	1.00	29.36	17132	12.18	0.255	0.681
		FM-32800 LD	1.184	1.216	1.52	30.65	27134	13.97	0.205	0.694
		MX-4955	1.510	1.547	2.53	27.95	13922	8.65	0.398	0.701
	MPCE-7	MX-4946 VC	1.374	1.440	0.67	35.68	29802	6.10	0.386	0.599
	MPCE-1,2,3	MX-4926	1.449	1.478	0.68	35.65	41850			
	MPCE 4 - 7	MX-4926	1.458	1.487	0.88	36.29				
Blast Tube, 90		Mean	1.454	1.484	0.78	35.97	41850	7.25	0.283	0.537
	MPCE-1	MX-4946	1.510	1.538	2.06	30.63	22546	9.32	0.464	0.790
	MPCE-2	MX-4926 VC	1.142	1.176	0.80	32.01		10.49	0.301	0.668
	MPCE-3	MX-4920 VC	1.411	1.455	0.48	27.95	28732	6.56	0.761	0.991
	MPCE-4	UF MX-134 LDR	1.207	1.239	1.83	41.19	22119	15.60	0.299	0.845
	MPCE-5	UF MX-4920	1.459	1.503	1.93	31.72	21108	9.28	0.582	0.907
	MPCE-7	MX-4946 VC	1.406	1.439	1.99	32.72	27145	8.22	0.496	0.784

Fig. 10B

Location	Motor	Material	Bulk Density, gm/cc	Specific Gravity	Residual Volatiles, wt%	Resin Content, wt%	Compressive Strength, psi	Norm. Erosion mils/s	Norm. Char, inches	Thad, inches
Aft Exit Cone	MPCE-1	MX-4946	1.463	1.483	0.65	36.45		4.22	0.193	0.341
	MPCE-2	MX-4926 VC	1.097	1.144	0.39	31.83		5.42	0.269	0.459
		MX-4920 VC	1.424	1.468	0.67	28.01		3.05	0.219	0.326
	MPCE-3	UF MX-4920	1.458	1.504	2.84	28.44	18718	6.73	0.254	0.677
		UF MX-4920 VC	1.368	1.415	1.42	33.73	22534	6.37	0.292	0.991
	MPCE-4	UF MX-134 LDR	1.212	1.243	1.85	40.97		4.54	0.272	0.431
		UF MX-4920 VC/PC	1.324	1.396	0.06	31.66	20583	4.57	0.344	0.504
	MPCE-5	FM-32800 LD/LF	1.098	1.190	0.80	27.45	16646	4.11	0.285	0.429
		UF MX-134 LDR PC	1.212	1.245	2.02	42.29	16759	4.15	0.258	0.400
	MPCE-6	MX-4926 VC/PC	1.084	1.154	0.00	30.93	18195	4.93	0.299	0.525
		FM-32800 LD/LF PC	1.127	1.213	0.46	28.10	7748	4.94	0.365	0.443
	MPCE-7	MX-4955 VC	1.371	1.428	0.17	27.02	16872	3.42	0.398	0.484
		MX-4946 VC	1.323	1.412	0.13	35.44		3.24	0.450	0.534

Fig. 11

Material Description	Bulk Density, gm/cc	Across Ply Tensile, psi		Full Tensile Stength, psi	Permeability, Log [Darcy's]		Shear (Torsion), IL, psi	Open Porosity, %	Max Peak Height in AP Th. Expan, 10^{-3} in./in.
		Ambient	750°F		Across-ply	Fill			
NARC HRPF	1.464	3720 ± 332 (8.9)	326 ± 34 (10.5)	20770 ± 2408 (11.6)	−15.67 ± 0.41	−15.47 ± 0.43	5760 ± 888 (15.4)	= 0.5	
MX-4926 VC	1.168	2222 ± 75 (3.3)	823 ± 31 (3.8)	13025 ± 425 (3.3)	−12.27	−10.24	3318 ± 31 (0.92)	14.67	23 @ 1100
UF MX-134 LDR (1.2)	1.233	1258 ± 60 (4.7)	46 ± 12 (25.3)	38225 ± 1125 (2.9)	< −20	< −20	2215 ± 7 (0.32)	0.66	34 @ 500
MX-4920 VC	1.337	846 ± 38 (4.4)	156 ± 40 (25.5)	34100 ± 2950 (8.6)	−12.00	−9.77	2782 ± 84 (3.03)	8.89	33 @ 1000
UF MX-4920	1.516	632 ± 8 (1.2)	151 ± 8 (5.5)	43750 ± 704 (1.7)	< −20	−12.28	3013 ± 114 (3.78)	0.56	38 @ 550
FM-32800 LD/LF									
FM-32800 LD									

Fig. 12

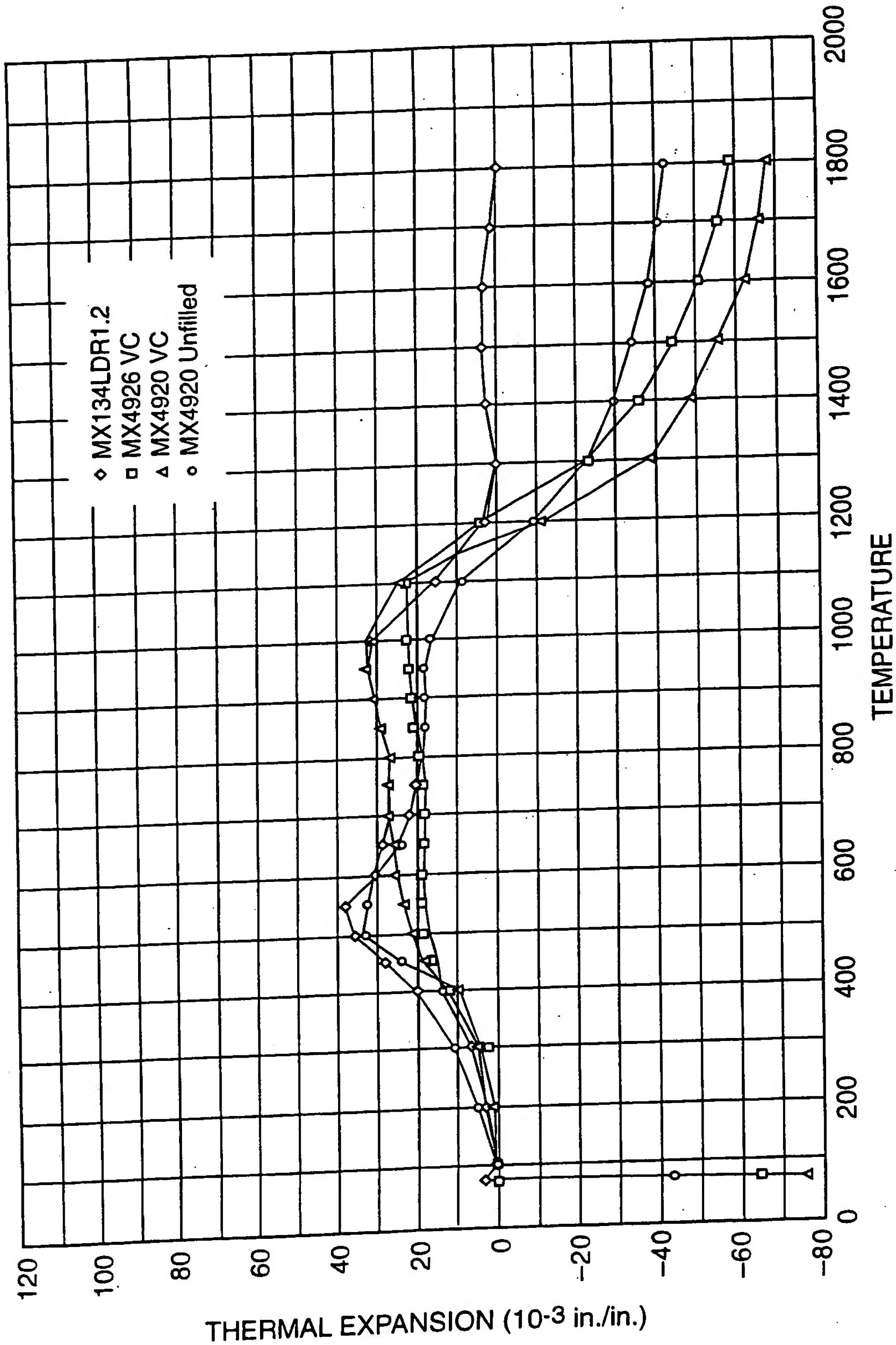

MX134LDR1.2
MX4926 VC
MX4920 VC
MX4920 Unfilled
TEMPERATURE
(°F)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
THERMAL EXPANSION (10-3 in./in.)
120
100
80
60
40
20
0
-20
-40
-60
-80

Fig. 13

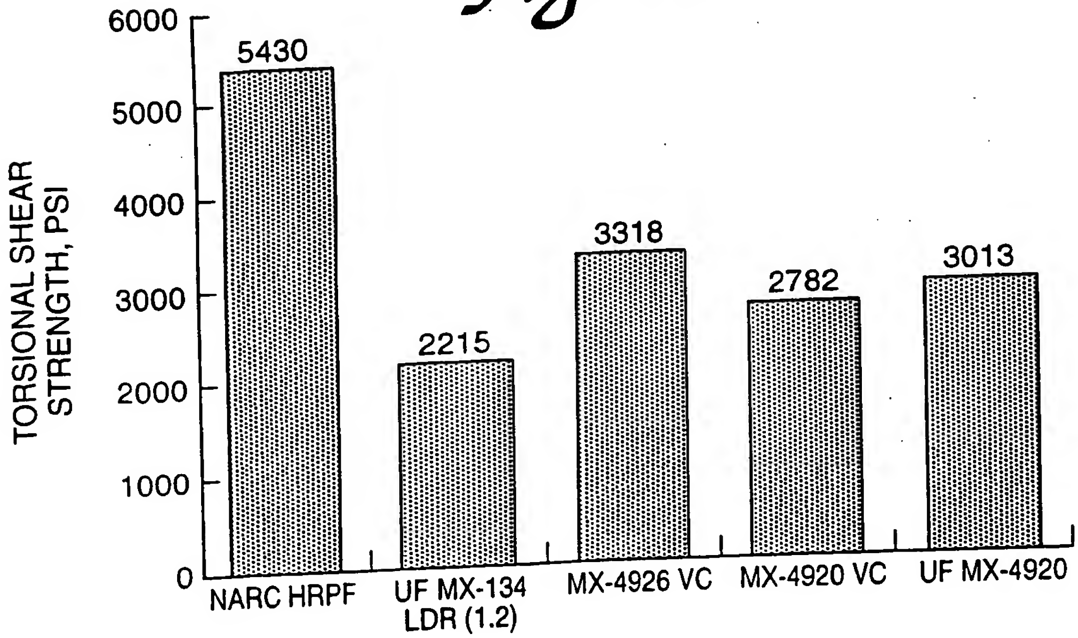

TORSIONAL SHEAR STRENGTH, PSI
6000
5000
4000
3000
2000
1000
0
5430
2215
3318
2782
3013
NARC HRPF
UF MX-134 LDR (1.2)
MX-4926 VC
MX-4920 VC
UF MX-4920

Fig. 14

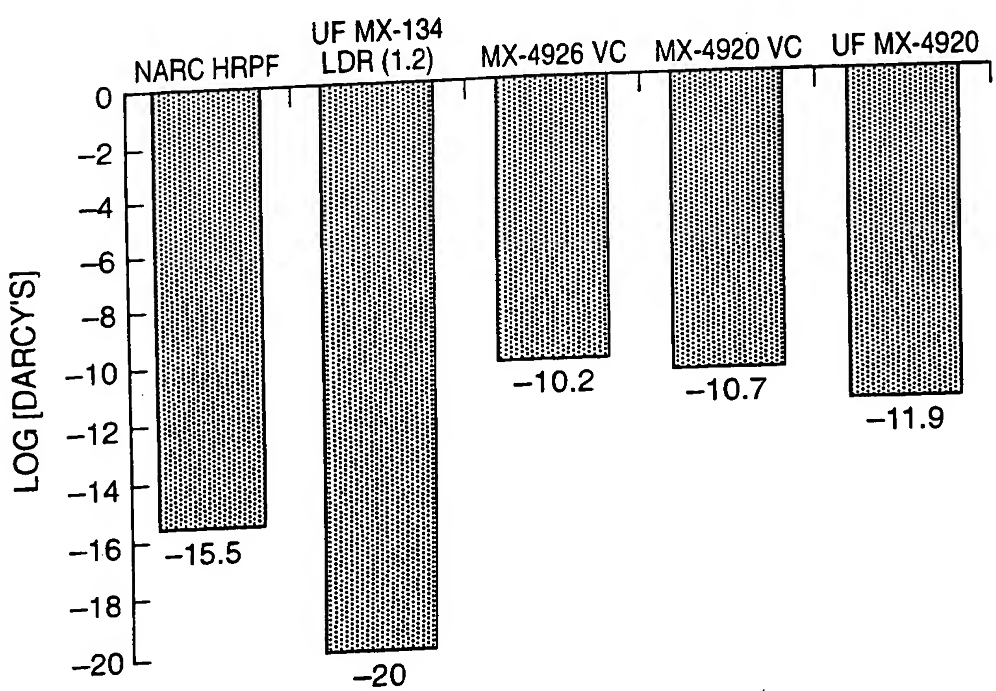

LOG [DARCY'S]
0
−2
−4
−6
−8
−10
−12
−14
−16
−18
−20
NARC HRPF
UF MX-134 LDR (1.2)
MX-4926 VC
MX-4920 VC
UF MX-4920
−15.5
−20
−10.2
−10.7
−11.9

Fig. 15

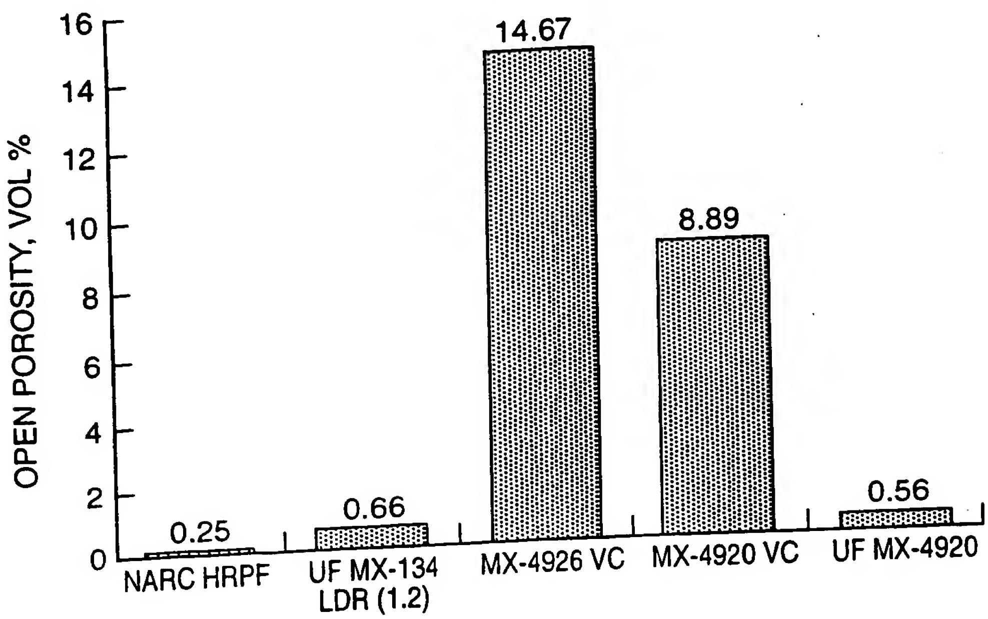
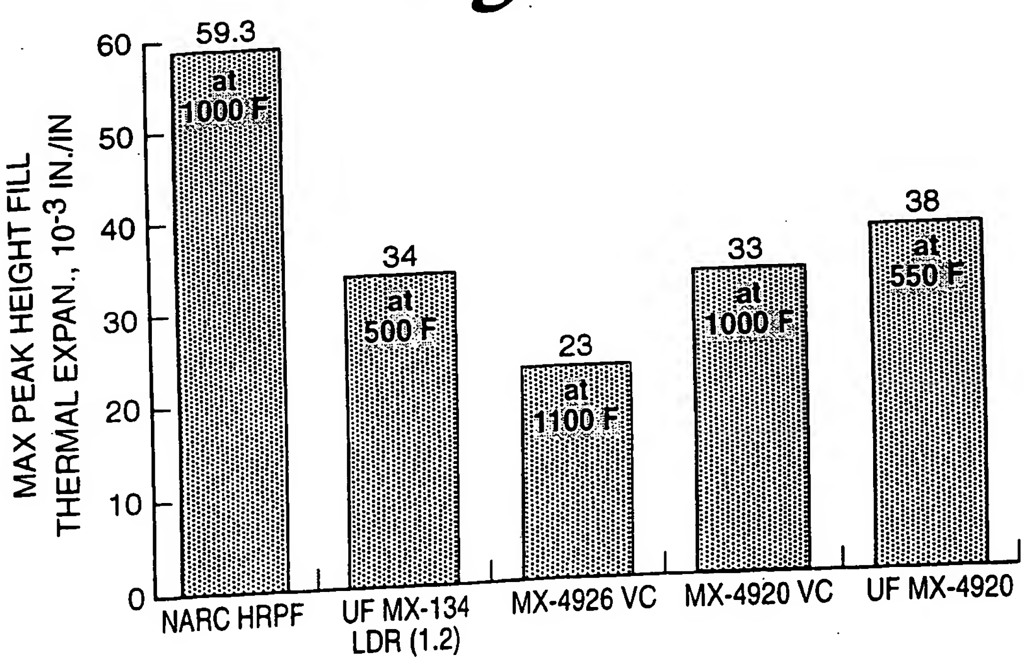

OPEN POROSITY, VOL %
16
14
12
10
8
6
4
2
0
0.25
0.66
14.67
8.89
0.56
NARC HRPF
UF MX-134 LDR (1.2)
MX-4926 VC
MX-4920 VC
UF MX-4920

Fig. 16


MAX PEAK HEIGHT FILL THERMAL EXPAN., 10-3 IN./IN
60
50
40
30
20
10
0
59.3
at 1000 F
34
at 500 F
23
at 1100 F
33
at 1000 F
38
at 550 F
NARC HRPF
UF MX-134 LDR (1.2)
MX-4926 VC
MX-4920 VC
UF MX-4920

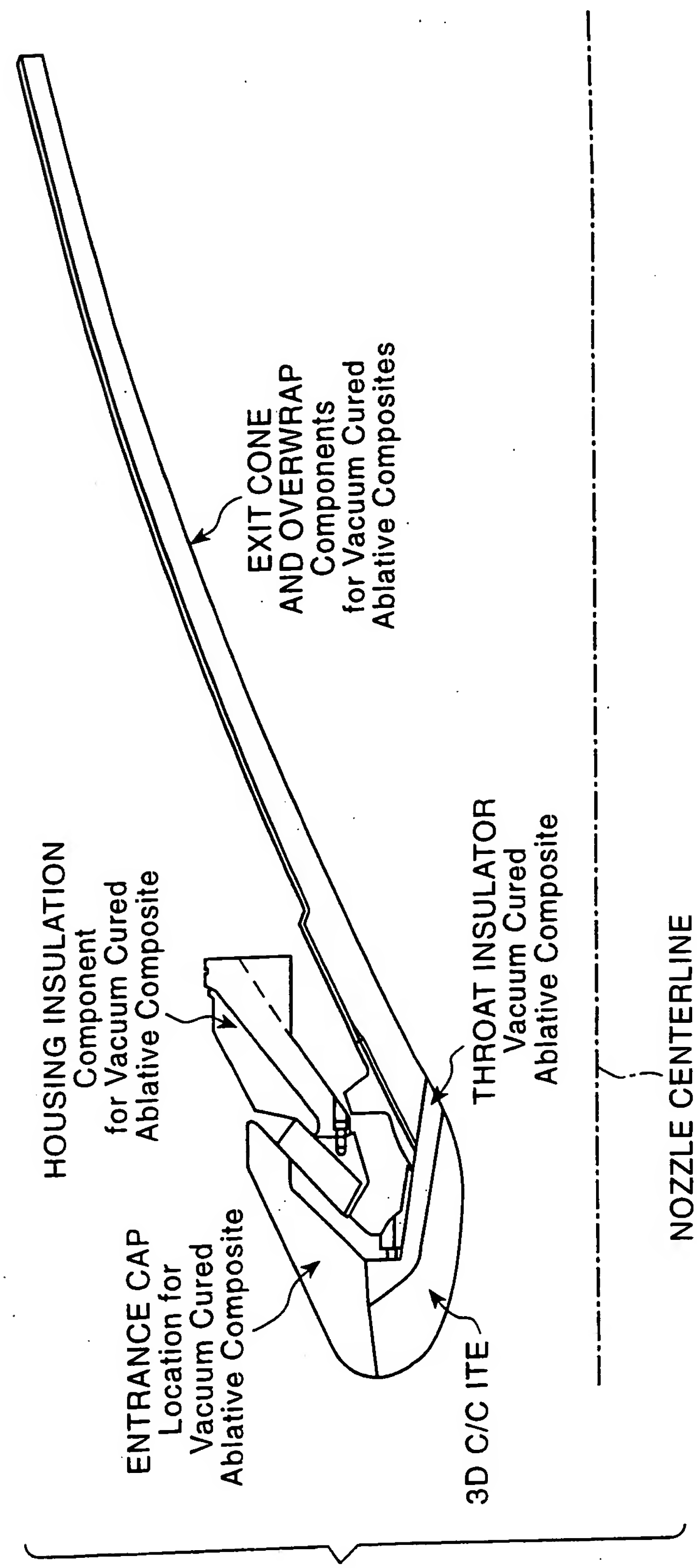

EXIT CONE
AND OVERWRAP
Components
for Vacuum Cured
Ablative Composites
HOUSING INSULATION
Component
for Vacuum Cured
Ablative Composite
THROAT INSULATOR
Vacuum Cured
Ablative Composite
NOZZLE CENTERLINE
ENTRANCE CAP
Location for
Vacuum Cured
Ablative Composite
3D C/C ITE

Fig. 17